International Journal of Modern Physics E

A new global alignment for PHENIX muon arms

C. Silvestre
Dapnia, CEA Saclay (France), for the PHENIX Collaboration
silvestre@in2p3.fr

Received (received date)
Revised (revised date)

The tracking efficiency of a spectrometer depends notably on the precise knowledge of its detectors position. The detector alignment is optimal when the distribution of the differences between the hit position measured in each detector and the one given by the track fit is centered on zero and has a minimal width. This was originally achieved by hand iteratively, which, due to the large number of *independent* detectors, is a difficult work and may not converge to the optimal solution. A new global alignment method has been developed at DESY and is now being applied to the PHENIX muon arms. The algorithm calculates the best set of alignment parameters for all detectors using all the available tracking information (independence of the tracks, same set of alignment parameters for all tracks) in order to minimize the sum of the tracks χ^2. Simulated data are used to validate the new alignment method with a larger set of parameters and including more detectors than the existing method. Applying the algorithm on real data with a limited set of alignment parameters shows an improvement over the existing alignment and validates its use for future data taking.

1. Introduction

The PHENIX experiment at RHIC aims to identify and study the properties of the Quark Gluon Plasma possibly formed in ultra relativistic heavy ion collisions. It consists of two central spectrometers located at mid rapidity ($|y| < 0.35$) and two muon arms at forward rapidity ($|y| \in [1.2, 2.4]$). Opening the muon arms or turning on the magnetic field can move slightly the detectors. A precise alignment procedure based on the data is needed to correct the theoretical detector position so that it matches its real position. The quality of this procedure has a direct impact on physics results since it can improve the tracking efficiency and allows the use of tighter analysis cuts to discriminate the signal from the background.

Up to 2005 data taking (Run 5) the muon arms are aligned using an iterative, manual method. After fixing a set of (possibly misaligned) detectors to reconstruct the tracks, the residuals in the remaining detectors (differences between the measured hits in a detector and the track extrapolation to this detector) are calculated. The residuals distributions are centered manually to zero by changing each detector position, and rerunning the reconstruction until a sufficient number of distributions are well centered. Besides not being automatized, this method has some drawbacks:

it uses only the mean value of each residual distribution and thus requires a lot of data; it is time consuming since the number of iterations is function of the number of detectors and alignment parameters; finally, it is not guaranteed to converge.

A global alignment method, Millepede, has been developed at DESY [1]. It looks for the best alignment parameters without iterations using a large number of tracks simultaneously and taking advantage of all available information for each track. When it would usually take a lot of computing time to invert a matrix of such dimensions, the authors derived a way to transform it into a lot of smaller matrices so that the calculation becomes worth doing. Millepede is being adapted to the PHENIX muon arms using field-off data for which the tracks are straight.

2. A global alignment

2.1. *The PHENIX muon spectrometers*

Each muon arm [2] consists of a muon tracker (MuTR), which measures the charged particles momentum, and a muon identifier (MuID), which identifies muons by matching the particle momentum to the penetration depth in the detector (left panel of Fig. 1). The MuTR is composed of threes stations, with respectively three, three, and two gaps, each one made of two cathode planes. One cathode is divided into eight octants. A total of 576 detectors is considered in the algorithm for the MuTR. The MuID is composed of five planes separated with layers of absorbers that help reducing the number of hadrons. Each plane is divided into six panels consisting in horizontal and vertical Iarocci tubes. In total, there are 716 independent detectors in the muon spectrometers.

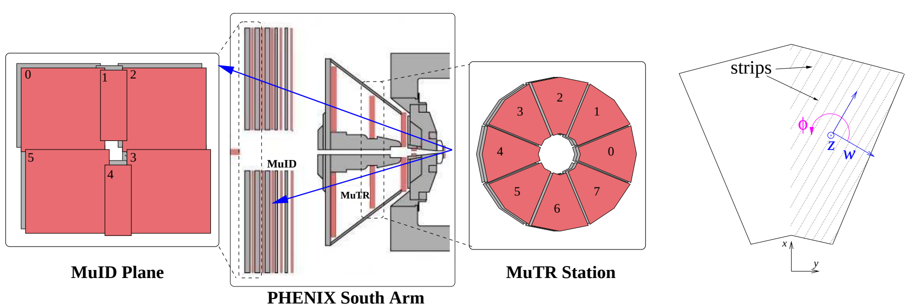

Fig. 1. Left: The PHENIX muon South spectrometer. Right: alignment parameters in a half octant.

2.2. *Alignment parameters*

The alignment parameters α_a represent the possible misalignments of the detectors with respect to their theoretical positions. Right panel of Fig. 1 illustrates the alignment parameters in a half octant of the MuTR: δw is a translation perpendicular to the strips, $\delta\phi$, a rotation around the beam axis, and δz, a translation along the beam. The following study focuses on δw.

2.3. *Track minimization*

The track parameters α_t characterize the position of a track in the detector, which, without magnetic field, is defined by (x_0, y_0) the track position at z_0 and $(t_{x,0}, t_{y,0})$ the track slope. At z_j, the track coordinates are:

$$\begin{cases} x_j = x_0 + t_{x,0}(z_j - z_0) \\ y_j = y_0 + t_{y,0}(z_j - z_0) \end{cases} \tag{1}$$

The distance between the track position w_j measured by the detector j and the position given by the fit is:

$$F_j = cos\phi[x_0 + t_{x,0}(z_j - z_0)] + sin\phi[y_0 + t_{y,0}(z_j - z_0)] - (w_j - \delta w_j) \tag{2}$$

With ϕ being the angle between w and x, and δw_j the possible misalignment of the detector j along w, which is introduced as a correction to the measured position. This distance is used to form the track χ^2, which has to be minimized in order to get the best set of alignment and track parameters:

$$\chi^2 = \sum_{j=1}^{N_{det}} \frac{|F_j(w_j, \alpha_t, \alpha_a)|^2}{\sigma_j^2} \tag{3}$$

With σ_j being the resolution of the detector j. Minimizing Eq. 3 is achieved through the cancellation of the partial derivatives.

2.4. *Global minimization*

When considering both alignment and track parameters, the χ^2 of several tracks must be minimized simultaneously:

$$\chi^2 = \sum_{i=1}^{N_{tracks}} \chi_i^2(\alpha_t^i, \alpha_a) \tag{4}$$

Where each track χ^2 is given by Eq. 3. Eq. 4 has a different set of track parameters for each track, but a unique set of alignment parameter per detector. Using this property, the matrix equation resulting from the cancellation of the partial derivatives of Eq. 4 becomes:

$$\begin{pmatrix} \sum C_i & \dots & G_i & \dots \\ \vdots & \ddots & 0 & 0 \\ G_i^T & 0 & \Gamma_i & 0 \\ \vdots & 0 & 0 & \ddots \end{pmatrix} \begin{pmatrix} \alpha_a \\ \vdots \\ \alpha_{t,i} \\ \vdots \end{pmatrix} = - \begin{pmatrix} \sum b_i \\ \vdots \\ \beta_i \\ \vdots \end{pmatrix} \tag{5}$$

Where C_i and b_i depend on derivatives of F_j with respect to alignment parameters only, $\partial F_j/\partial\alpha_a$, Γ_i and β_i depend on derivatives of F_j with respect to track parameters only, $\partial F_j/\partial\alpha_t$, and G_i includes cross-terms of type $(\partial F_j/\partial\alpha_a)(\partial F_j/\partial\alpha_t)$.

The time needed to invert the matrix is proportional to the square of its dimension. Using 100k tracks to align the 716 independent detectors along w gives a dimension of 400716, which may lead to numerical divergences. However, using the independence of the track parameters, the Γ_i matrices can be inverted separately and the problem can be reduced to the inversion of a smaller matrix C', which dimension is equal to the number of alignment parameters, leading to $\alpha_a = C'^{-1}b'$, with $C' = \sum_i C_i - \sum_i G_i \Gamma_i^{-1} G_i^T$ and $b' = \sum_i b_i - \sum_i G_i \Gamma_i^{-1} \beta_i$. The time needed to invert the Γ_i matrices grows linearly with N_{tracks}, whereas for the C_i matrices, it is track independent and only grows with the number of detectors.

3. Algorithm validation

Simulations are used to validate the algorithm. Misalignments are introduced manually before reconstructing the tracks and are compared to the misalignments found by Millepede when aligning the MuTR and the MuID simultaneously (Fig. 2). MuTR station 0, gap 1 and station 1, gap 0 are fixed to avoid global translations along (Ox) and (Oy) as well as local transformations proportional to the detector position along z.

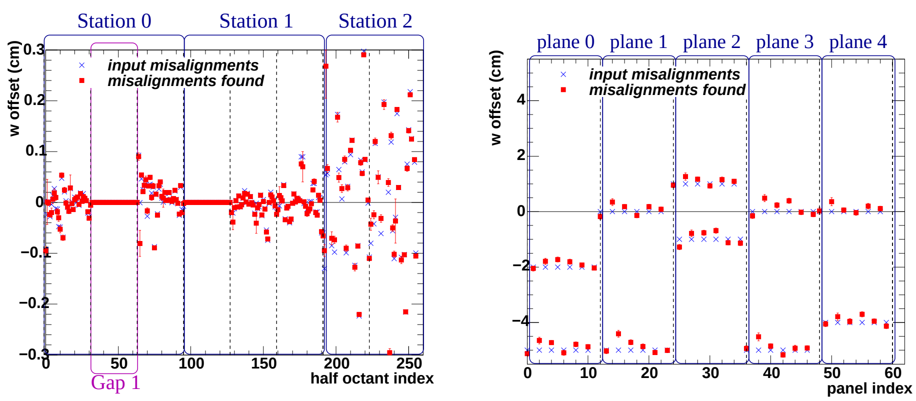

Fig. 2. Left (right): w offsets in each half octant (panel) of one MuTR (MuID) arm: in blue the misalignment introduced manually in the code; in red the corrections found by Millepede.

The algorithm finds the input misalignments with a precision of about 200 μm (1 mm) for the MuTR (MuID), using 7k (140k) tracks in each half-octant (panel). The alignment quality is better than the detectors resolution (about 500 μm for the MuTR, and 1 cm for the MuID). It can be further improved by using more tracks.

4. Results on real data

Fig. 3 illustrates the misalignments found by Millepede looking at real data: about 1300 (3000) tracks per half-octant (panel) are used to get an alignment precision of about 500 μm (1 cm) in the MuTR (MuID). Found misalignments range from less than 1 mm to 1 cm in the MuTR, and up to 4 cm in the MuID. MuTR station 2 has larger misalignments than the other stations. The MuID error bars are larger because of its poorer resolution. Plain vertical lines in the MuID indicate planes that have no hit contributing to the tracks, making them impossible to align.

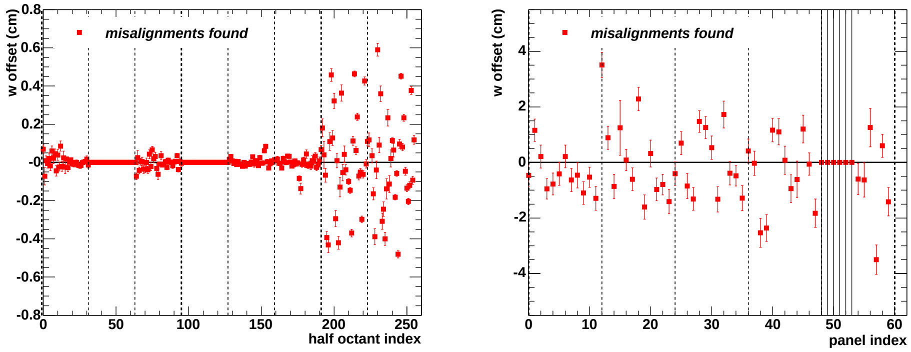

Fig. 3. Left (right): w offsets from real data found by Millepede in each half octant (panel) of one MuTR (MuID) arm.

5. Comparison with the previous alignment

Millepede is applied on Run 3 p+p field-off data to align the MuTR and the MuID. It takes less than two days to get Millepede corrections. Results (blue squares) are compared to the last set of corrections found with the traditional method for Run 4 Au+Au analysis (black circles) and to the case where no corrections are applied (red triangles). The following observables demonstrate the quality of Millepede's alignment.

5.1. *Residuals*

Left panel of Fig. 4 compares the means of the residual distributions in each half octant of one MuTR arm for the three configurations. Right panel of Fig. 4 represents the distribution of the mean value of the residuals in the MuTR arm, thus corresponding to the projection of left panel of Fig. 4 on the ordinate axis. On average, the mean values are better centered on zero and the width is smaller when using Millepede corrections. The offsets are -19 μm without corrections, -18 μm using the Au+Au corrections and 2 μm with Millepede, and the width are 0.20 mm, 0.18 mm and 0.13 mm, respectively.

5.2. *Matching between the MuID and the MuTR*

Fig. 5.2 represents the distance between the road in the MuID and the track in the MuTR extrapolated to the first gap of the MuID (DG0) as a function of the track momentum along the beam axis (pz). The smaller is DG0, the better is the MuTR alignment with respect to the MuID. Millepede's configuration (squares) is close to the simulations with a perfect alignment of the detectors (crosses).

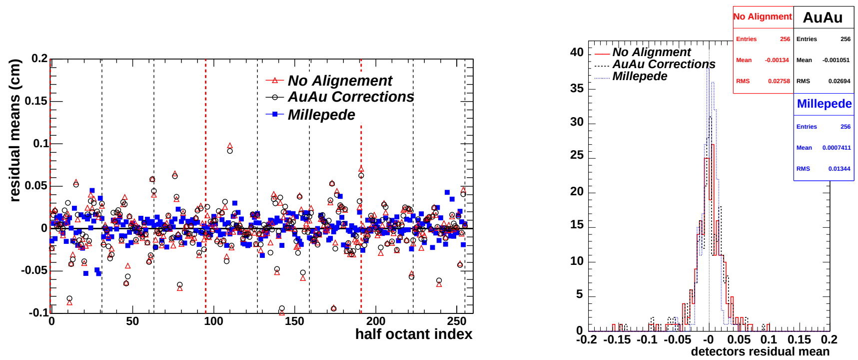

Fig. 4. Comparison of the half-octant residuals without alignment (triangles and dots), before using Millepede (circles and dashed line), and with Millepede's corrections (squares and straight line). Left: mean value of the residual distributions. Right: distribution of the residual means.

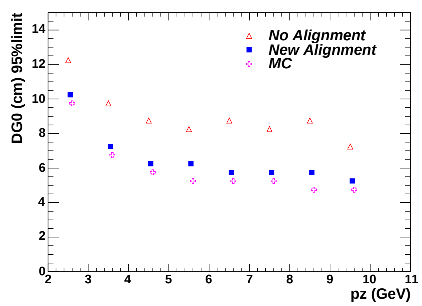

Fig. 5. DG0 distribution as a function of p_z without alignment (triangles), with Millepede (squares) and with a perfect simulated alignment (crosses).

6. Conclusions

Millepede algorithm has shown positive results when applied to PHENIX muon arms, both in terms of performance and computing time. The global alignment corrections found by the algorithm will be used for future runs, starting from Run 6. Other parameters (θ and z) will be studied using the much larger Run 6 data sample. The algorithm will also be applied on field-on data to derive first order corrections to the field-off alignment and thus provide the best corrections in real data taking conditions.

Acknowledgements

I would like to thank QM2006 organisation to having fund my participation to the conference.

References

1. V. Blobel and C. Kleinwort, Conference on Advanced Statistical Techniques in Particle Physics, Durham, 18-22 March 2002.

2. K. Adcox *et al.*, *NIM* **A499**, 469 (2003)